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Review Article

The Magnetic Nanomaterial Biofunctions in Cancer Diagnosis and Therapy

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Magnetic nanomaterials have recently emerged, playing an increasingly essential role in life science and biomedicine fields, and they exhibited promising potentials in cancer diagnosis and therapy. Also, their use as contrast agents improved various cancer diagnostic imaging sensitivities and accuracy. Magnetic nanomaterials are also exploited as targeted drug carriers to increase the sensitivity and reduce the side effects of chemotherapeutic drugs. Herein, we reviewed the preparation, characterization, and surface modification of various magnetic nanomaterials and their cancer diagnosis and therapy applications.

1. Introduction

Cancer remains the second most common cause of death, and its morbidity and mortality are increasing in China; this is mainly because most tumor onset is subtle and challenging to be detected in the early stage [1]. Most diagnosed cancer patients are already in advanced and late stages; this hinders requisite curative effect. Besides, the primary cancer treatment includes surgery, chemotherapy, and radiotherapy [2]. However, the complete removal of the tumor tissue through surgical treatment is intractable. Various side effects and adverse reactions often accompany radiotherapy and chemotherapy. Moreover, tumors could evolve metastasis and drug resistance during progression or recurrence, which dramatically reduces the subsequent treatment effect [3]. Therefore, it is pivotal to identify new cancer treatments and prognostic methods.

The magnetic nanomaterial has newly emerged; they are characterized by small particle size, superparamagnetism, and surface modification ease [4]. Magnetic nanoparticles can be employed in different aspects, combined with biomolecules, fluorescent probes, and antitumor drugs; currently, they are used as magnetic resonance contrast agents, targeted drug delivery, and in magnetic fluid hyperthermia [5]. The Fe_3O_4 core/shell/crown functional magnetic nanomaterials have achieved good therapeutic results in bladder cancer in vitro [6]. The gadolinium-doped iron oxide nanoparticles (GdIO NPs) showed good potential in magnetic resonance imaging and achieved promising results in breast cancer treatment in vitro [7]. The superparamagnetic PEG-modified La1-xSrxMnO3 (LSMO) magnetic nanoparticles exhibited favorable potency in magnetic resonance imaging and tumor magnetic fluid hyperthermia [8].

Herein, concerning the recent research on magnetic nanomaterials in tumor therapy, the preparation, surface modification, characterization analysis of magnetic nanomaterials, and their applications in tumor-targeted therapy and diagnosis are briefly reviewed.

2. Preparation and Characterization of Magnetic Nanomaterials

2.1. Preparation of Magnetic Nanomaterials. Fe3O4 and γ-Fe2O3-based nanoparticles are currently applicable in living organisms; this nanoparticle composition is beneficial as the iron-containing cells can maintain the intracellular environment's stability by absorbing, storing, and excreting iron atoms [9]. Also, iron can be easily removed from the body, allowing a comparatively large iron dose since the oxidative stress reaction is absent. Iron oxide nanoparticles are high safe [10]. Preparing magnetic nanomaterials are divided into physical and chemical approaches; this includes grinding, ultrasonic, and plasma methods. Currently, the preparation methodology includes hydrothermal synthesis, sol-gel, and forced hydrolysis and thermal decomposition [11].

2.1.1. The Coprecipitation Method. The coprecipitation is a convenient and straightforward method to obtain iron oxide particles; this is achieved by adding an alkaline solution to a salt solution of iron (Fe^{2+}/Fe^{3+}) in an inert gas atmosphere at room temperature. Its preponderance is that large amounts of iron oxide nanoparticles can be synthesized one time. However, the size of the magnetic nanomaterials obtained by the coprecipitation method is challenging to control, where the particle diameter distribution is relatively dispersed and tricky to be consolidated [12].

2.1.2. Sol-Gel and Forced Hydrolysis Techniques. In the sol-gel approach, molecular precursors in the solution are hydroxylated and condensed to obtain the initial nanoparticle solution. The initial solution is further condensed and set to be polymerized to obtain a three-dimensional wet gel of the metal oxide network. The wet gel characteristics are highly dependent on the structural treatment of the sol preparation. The method has advantages: materials can be customized, the size of particles is homogenous, and the reaction temperature is relatively low [13]. The γ-Fe_2O_3 nanoparticles obtained by the sol-gel method can be embedded in an inert, inorganic, and transparent silica matrix with high-temperature resistance. Sugimoto et al. reported that nanostructured oxides with various structures and compositions could be obtained following different preparation conditions, precursor properties, ion source, and pH [14].

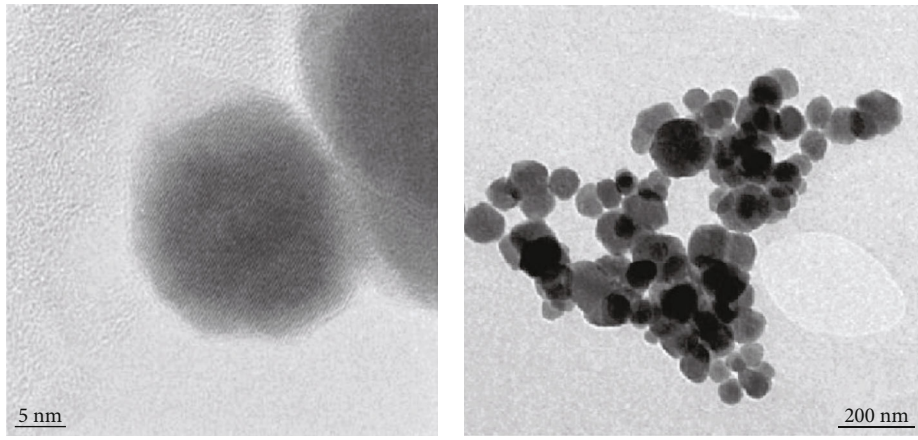
2.1.3. Thermal Decomposition Method. Thermal decomposition is a commonly used approach in the biomedical field to prepare precise nanoparticles. This method helps control the nanoparticles' size and morphology and control the yield [15]. Recently, there are two main types of thermal decomposition: first, oxidizing the metal carbonyl precursor in the air after or during thermal decomposition [16]. The second is precursor decomposition with a cationic metal without a reducing agent [17]. Many small-sized monodisperse nanomagnetic crystals can be synthesized by dissolving metal-organic compounds in a high-boiling organic solvent with stable surfactant and thermal decomposition. Sun et al. discovered the broad applications of the organometallic precursors of acetyl-acetone; these precursors included iron, manganese, and nickel acetylacetonate [18]. The surfactants used in this approach are usually fatty acids, oleic acid, and hexadecyl-amine [19]. Hyeno et al. have experimentally demonstrated that decomposing organometallic compound precursors by thermal decomposition with surfactant can achieve small and even nanoparticles with good crystallinity and dispersibility. The ratio of organometallic compound precursors, solvents, surfactants, temperature, time, and oxidation are all keys to control the nanoparticles diameter and morphology accurately [20]. This approach has a significant drawback as the final product is organic soluble nanoparticles, limiting its application in the biological field. Moreover, the produced nanoparticles by thermal decomposition often require further surface treatment, and the reaction process is intricate and requires high temperature [21].

2.1.4. Hydrothermal Synthesis Method. In this method, the reaction needs to be done in a reactor or autoclave under high pressure and temperature, 2000 psi, 200°C., respectively. Laurent used the hydrothermal approach in the preparation of Fe_3O_4 nanoparticles [22]. Different nanoparticles have been prepared by hydrothermal synthesis as it has better crystallinity over other techniques. However, different hydrothermal synthesis conditions may cause different particle crystallinities and affect their magnetism. The well-crystallized particles are thinner, have a narrower surface layer and cation distribution space, and their superparamagnetic relaxation is low.

2.1.5. Microemulsion. The water molecules have a spherical shape in the water-in-oil microemulsion and are surrounded by the surfactant molecules. The microemulsions can function as cages to produce nanoparticles, reducing the average particle size during collision and aggregation [23]. Thus, the nanoparticles' size can be controlled and adjusted by changing the size of water droplets, determined by the molar ratio of water to surfactant. This method can be used to control the size of the synthesized nanomaterial within a specific range. However, since the nanoparticles' size and shape generally vary within a relatively large range, the produced nanoparticles may be spherical, rectangular, or tubular [24]. Besides, compared with other methods, such as thermal decomposition and coprecipitation, the nanoparticles prepared by the microemulsion technique are less efficient, and the synthesis process is too complicated. Therefore, the microemulsion approach is mainly used in the laboratory.

2.2. Characterization and Detection of Magnetic Nanomaterials. The nanomaterials are initially characterized by their size and shape; these are crucial indicators to validate their production process. The transmission electron microscopy and high-resolution transmission electron microscopy are used to determine the nanomaterials' size and shape, and they require an ultrathin specimen. Their output data comprises grouped diffracted beams called a phase-contrast image (Figure 1) [25].

The crystal characteristics of the magnetic nanomaterial can also be detected by 40Kv, 30 mA-Cu Kα X-ray. The unique iron peak in the diffraction pattern demonstrates the irons as magnetic nanomaterials [26]. Ge and S used X-



(a) (b)

Figure 1: Nanomaterial's TEM image (a) and high-resolution TEM image (b).

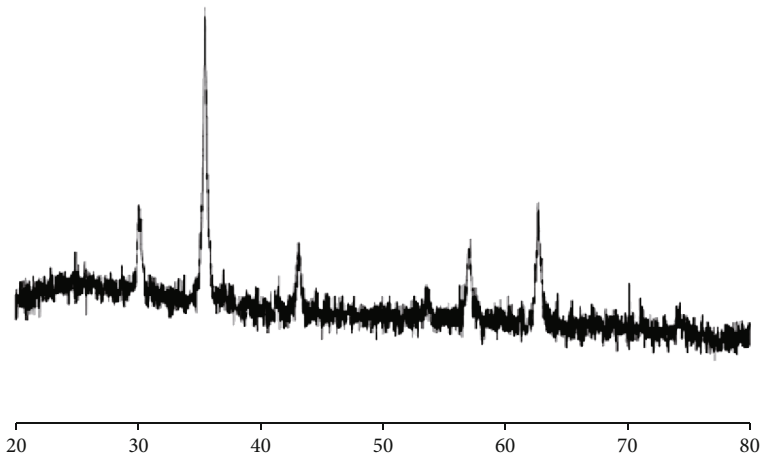


Figure 2: Typical map of iron oxide nanoparticles after analysis by X-ray diffraction.

ray diffraction to analyze the crystalization of magnetic nanoparticles in a powder state; they demonstrated that the magnetic nanoparticles without copolymer have six diffraction peaks at 2θ, 30.1, 35.4, 42.9, 52.7, 57.5, and 62.7 (Figure 2), indicating the presence of iron oxide at the corresponding peak [27].

The nanomaterial's magnetism is another critical characteristic. It is typically measured by a vibrating sample magnetometer, which can detect their magnetization changes with different field intensities. The nanomaterial's magnetism turns from the high baseline value to zero upon decreasing the applied field intensity. In that case, the iron oxide magnetic nanoparticles can be detected as a single crystal from the altered magnetic direction.

The chemical composition of the magnetic nanomaterials' functional ligands and polymers is determined using Fourier transform infrared spectroscopy. Bhattarai et al. detected a strong light emission from iron oxide nanoparticles in the low-frequency region (below $800\,cm^{-1}$) by Fourier transform infrared spectroscopy. Stabilizing the magnetic nanoparticles using cystic chitosan exhibited an alteration in the modified chitosan's infrared spectrum due to the interaction with iron oxide nanoparticles [28]. This amide change of the light corresponding band spectrum from high energy to low energy indicates the nitrogen linkage of iron oxide nanoparticles to the modified chitosan.

3. Surface Modification of Magnetic Nanomaterials

The magnetic nanomaterial surface modification alleviates its cytotoxicity and improves their biocompatibility and binding capability to active molecules or compounds. Therefore, magnetic nanomaterial surface modification promotes it as a powerful tool in the biomedical field [29]. The main purpose of surface modification includes improving the stability of magnetic nanomaterials in vitro and in vivo and also minimizing residual magnetism. During the nanomaterial surface modification, the provided functional group on the surface enables further derivatization and enhances the solubility in various solvents, thereby broaden their applications [30]. Different nanomaterial surface modifications determine their antifouling property and hydrodynamic size; they also

Table 1: Commonly used surface modification materials for magnetic nanoparticles.

	Material	Properties	Application
High molecular polymer	Dextran [70]	Good biocompatibility and biodegradability	Stabilize the colloidal solution and increase the time of nanomaterial circulation in the blood
	Polyethylene glycol (PEG) [71]	With good hydrophilicity, it does not cause an immune response and antigen-antibody reaction	Reduce the phagocytosis time of nanomaterials by macrophages and increase the circulation time of nanomaterials in the blood
	Polyvinyl alcohol (PVA) [72]	Good hydrophilicity, biocompatibility, superior film, and gel-forming ability	Improve the stability of the colloidal solution
	Polyacrylic acid [73]	Good water solubility	Improve the biocompatibility of nanomaterials and help nanomaterials adhering
Surfactant [74]	Oleic acid, lauric acid, Dodecylphosphoric acid, cetylphosphonic acid, hexadecylphosphonic acid, alkanesulfonic acid, various phosphates, etc.	With good biocompatibility, it is safe and nontoxic. Although soluble in water, it can be soluble in various organic solvents.	Improve the stability and biocompatibility of nanomaterials
Inorganic coating	Silica [75]	Good biocompatibility, safe and nontoxic, chemically stable	The nanomaterials are prevented from degrading and coagulating in the organism, making it easier to connect functional groups
	Gold [76]	Biocompatibility, optical, and magnetic properties for biological applications	Improve the stability of magnetic nanoparticles and maintain the magnetic moment of magnetic nanomaterials
	Carbon [77]	Stable chemical properties, good thermal stability, and good biocompatibility	Improve the stability of magnetic nanomaterials, improve the oxidation resistance and acid resistance of magnetic nanoparticles

play an important role in their biokinetics and biodistribution in vivo [31]. For instance, the nanomaterial's overall particle size must be significantly small to avoid being engulfed by the reticuloendothelial system (RES), a vital nonspecific immune system formed by macrophages residing in tissues and relatively large to avoid kidney clearance. Besides, proper surface modification can reduce the magnetic nanomaterials' surface toxicity and enable them to be enriched in specific regions, a prerequisite in tumor diagnosis and targeted therapy [32]. Furthermore, the appropriate nanomaterials' surface modification exhibits precision characteristics when coated with targeting ligands such as proteins, peptides, antibodies, or other small molecules. This unique conjugation of the magnetic nanomaterial to specific ligands promotes identifying certain molecular markers on the surface of malignant cells, allowing the magnetic nanomaterials to be specifically enriched in the tumors, providing a strong basis for their use in tumor diagnosis and treatment [33]. Moreover, magnetic nanomaterial-small molecule coupling can increase the affinity between the magnetic nanomaterials and the corresponding surface receptors of malignant cells. For instance, folic acid receptors are overexpressed in different human tumors, including ovarian, lung, breast, endometrial, kidney, and colon cancer. The recent applicable materials in surface modification include high molecular polymers, surfactants, and inorganic coatings. See Table 1 for details [34].

4. Magnetic Nanomaterials Applications in Tumor Diagnosis

4.1. Magnetic Nanomaterial Applications in Magnetic Resonance Imaging. Magnetic resonance imaging (MRI) is a widely used noninvasive medical diagnostic technique. MR image has unique advantages in diagnosing various tumors such as liver cancer, cervical cancer, ovarian cancer, glioma, and other tumors [35]. Magnetic resonance imaging uses radio frequency (RF) electromagnetic waves to motivate nuclear materials with nonzero spins in a magnetic field——-mainly hydrogen atoms——to generate nuclear magnetic resonance (NMR). The induction coil detection technology is used to obtain tissue relaxation information and proton density information (acquisition resonance signal). Finally, mathematical image reconstruction has been used in different techniques to construct magnetic resonance images [36]. During NMR imaging, the RF pulses are stopped to transmit the resonated hydrogen atom in the body. The relaxation process aims to restore the high energy nucleus to equilibrium, and the time experienced by this process is called the relaxation time. The relaxation time is divided into T1 and T2, where T1 is called longitudinal relaxation time, and T2 is called transverse relaxation time [37]. The currently used contrast agents are divided into T1 inhibitors such as paramagnetic metal ions Gd3+, Mn2+, etcetera, and

T2 inhibitors, including superparamagnetic and ferromagnetic substances. Due to the efficient magnetism of the magnetic nanomaterials, they have been broadly utilized in magnetic resonance imaging research. The superparamagnetic iron oxide (SPIOs) nanomaterials are famously used in MRI imaging; they significantly enhance the contrast of T2WI images. Currently, Daou et al. reported the use of nanoparticle alloys such as FePt and MnZeFe as MRI contrast agents [38].

4.2. Magnetic Nanomaterial Applications in PET-CT Imaging. Positron emission computed tomography (PET-CT) is a commonly used noninvasive clinical examination in the tumor diagnosis and prognosis. The chelated 2-fluoro-2-deoxy-D-glucose (18F-FDG) with small molecules or antibodies is a commonly used contrast agent [39]. In recent preclinical studies, the radioactive-labeled magnetic nanoparticles have been proved very promising in cancer diagnosis. It has three significant advantages compared with traditional imaging techniques: (1) the magnetic nanoparticles labeled with radioactive tracer possess precision targeting due to the EPR effect, (2) magnetic nanoparticles have a high surface to volume ratio, allowing the use of high-density radioactive labels, and (3) obtainable complementary multimodal imaging, for instance, utilizing different radionuclide nanoparticles in integrated imaging [40]. Pratt et al. found that chelating radionuclides on the surface of small and biocompatible magnetic nanoparticles improved the accuracy and specificity of early tumor diagnosis, also using the advantages of PET scan of displaying the changes in tissue functions [41].

4.3. Biofluorescence Imaging. Bioluminescence imaging obtains optical images given fluorescence characteristics changes. At the cellular level, fluorescent nanomaterials act as fluorescent probes enter the cells in both active transport and passive diffusion due to their small size; at the organism level, the nanoparticles enter the bloodstream, then exuded and enriched in the tumor lesion due to the high permeability of tumor blood vessels. CL et al. combined magnetic nanoparticles with fluorescent materials to prepare magnetic fluorescent nanocomposites that are both superparamagnetic and fluorescent. When the magnetic fluorescent nanocomposites are introduced into living cells, the fluorescence can be traced and controlled to be enriched at the desired location upon applying an external magnetic field, which dramatically improves the efficiency of cell imaging [42].

4.4. Hybrid Imaging Model. Different imaging techniques comprise certain advantages and disadvantages, and yet, there is no ideal technique. A single imaging technique cannot guarantee optimal performance in different cases. Nevertheless, hybrid imaging can integrate the advantages of several techniques to address the inherent limitations of a single imaging technique [43]. For instance, PET-CT is a renowned sensitive tumor diagnostic tool, while MRI can provide more anatomical information through high-resolution images [44]. Therefore, combining these two imaging techniques can provide higher sensitivity and more detailed anatomical information in tumor diagnosis. Nanomaterials can possess precision targeting properties through surface modification and could be used as contrast agents in imaging technology. Tracking the contrast agent's enrichment in the body helps determine surgery scope and facilitate the procedure, i.e., employing fluorescence imaging. It can also ensure whether tumor tissues are entirely removed or not, i.e., performing MRI analysis. Besides, the tumors' occurrence and progression can be tracked and identified, i.e., utilizing PET-CT [45]. The recent hybrid imaging techniques are MRI/fluorescence imaging and PET-CT/MR imaging [46]. Therefore, diagnosis accuracy can be improved, and better cancer therapeutics can be developed.

5. Magnetic Nanomaterial Applications and Research in Tumor Therapy

Recently, radiotherapy and (or) chemotherapy are commonly used as initial treatment combined with surgery [47]. However, different factors, including genetic alterations, could promote tumor drug resistance by dysfunctioning the cellular transport mechanisms and reducing drug efficiency and cellular detoxification capability. These adverse effects restrict the administrated drug dosage to patients [48].

5.1. Magnetic Nanomaterial Applications as Drug Carriers. With the vigorous development of the nanotechnology, has more and more attention has been paid to nanocarriers. Nanoparticles have good biocompatibility and less immune reaction, coupling with other ligands or antibodies after easily into the organization or the specific antigen specificity and cell surface receptors, or be swallowed up by the target cell into the cell, the DNA of the implementation of transhipment. It is also released in cells with high gene transfer efficiency [49]. Magnetic nanoparticles, especially paramagnetic and superparamagnetic ferrite nanoparticles, have become an objective material in drug carriers' development [50]. The ferrite nanoparticles are primarily made of iron-containing particles or other active ingredients containing iron. It has been proven that ferrite nanoparticles exhibit decent biocompatibility and can be entirely metabolized. Moreover, it has robust and distinct drug-loading capabilities. Various antibodies, antigens, small molecules, polypeptides, and active proteins can be loaded on the modified nanoparticles' surface. Different examples can present the mode of action of the modified nanoparticles; for instance, through the antigen-antibody reaction in the body or under the guidance of an external magnetic field, these targeted antigen-loaded nanoparticles are enriched in the tumor lesions, concentrating the accumulation of the antibodies to the target tumor cells to achieve the optimal therapeutic potential [51]. Recently, the nanoparticle preparation process is relatively mature. A complex combination of tumor suppressor genes, antitumor monoclonal antibodies, and antitumor drugs such as doxorubicin, paclitaxel, and cisplatin, can be integrated to establish a distinct advantageous microcarrier system that possesses magnetism, bioapplicability, and capability to cross the blood-brain barrier. Following the previously mentioned basis of establishing microcarrier systems,

the "three-stage carrier rocket theory" is proposed to provide a basis for tumor-targeted therapy [52]. Magnetic nanomaterials are proposed in the 1970s as carriers in targeted therapeutics, which has been recently shown as an ideal application [53]. For instance, the MNP-HP-CP complex has been synthesized using magnetic nanoparticles (MNPs) coated with heparin (HP) and embedded with cisplatin (CP) by solvent evaporation and emulsification crosslinking. The MNP-HP-CP complex intake by human ovarian cancer cells CP70 promoted cell apoptosis [54]. These findings proved the feasibility of magnetic nanomaterials as drug carriers. It has also been shown that this magnetic nanomaterial composite is biocompatible, minimally cytotoxic, and sustains the release of cisplatin [55].

Although paclitaxel is an essential drug in ovarian cancer treatment, its high administrated dose may cause severe allergic reactions and dramatically limits its therapeutic effect [56]. On the other hand, the polyethylene glycol- (PEG-) triethoxysilane (APTES)- (PA-) modified magnetic nanomaterial packed with paclitaxel and doxorubicin precisely delivered the paclitaxel and doxorubicin to tumor cells, alleviating adverse side effects and sustaining the drug concentration in the tumor tissue [57] and increasing the therapeutic effect of paclitaxel.

5.2. Magnetic Nanomaterial Applications in Tumor Hyperthermia. Tumor hyperthermia refers to heat augmentation tumor treatment. Tumor hyperthermia is renowned as the fifth therapeutic approach after surgery, radiotherapy, chemotherapy, and immunotherapy [58]. It employs physical energy to elevate a particular or whole-body heat so that the tumor tissue temperature rises to a certain level and duration. Within specific time and temperature, tumor cells die without affecting healthy cells due to the different temperature tolerance between healthy and tumor cells [59]. When the temperature range is 40-42°C, the tumor cell fluidity is enhanced, the structure is weakened, and the viability is lost. High temperature injuriously affects the tumor cells' endoplasmic reticulum, lysosomal membrane, and mitochondrial membrane, promoting cell death. The high temperature also inhibits the polymerase and ligase activity, repressing the synthesis of nucleic acids. Besides, the tumors' surrounding blood vessels are characterized by abundant blood flow, abnormal vascular structure, twisted blood vessel shape, and high blood flow resistance and enable blood vessel thrombosis or occlusion. During hyperthermia, healthy and tumor tissues' temperature increases; however, because of the optimal blood circulation in healthy tissues rather than tumor tissues, the heat poorly dissipated and eventually rises, killing tumor cells. Jordan et al. reported the unprecedented use of magnetic nanoparticles in tumor hyperthermia and proposed magnetic fluid hyperthermia (MFH) conceptualization [60]. The magnetism and adequate water solubility of magnetic fluids fostered its uses in clinical applications. Applying an external alternating magnetic field (AMF) over magnetic nanoparticles converts the magnetic energy into heat and steadily increases local tumor tissue temperature, thereby suppressing tumor cell growth [61]. Studies have shown that compared to paclitaxel cytotoxicity under normal body temperature, 30 minutes of constant heating at 43°C can significantly increase paclitaxel cytotoxicity by 10-100 times [62]. Secord et al. reported that the PEG-modified liposome nanoparticle-adriamycin complex combined with abdominal hyperthermia exhibited better precision, outcome, and drug uptake in tumor tissues [63].

5.3. Magnetic Nanomaterial Applications in Photodynamic Tumor Therapy. Photodynamic therapy is a new therapeutic technique that combines photosensitizer with the corresponding illuminant to destroy tumor tissue through selective photodynamic reactions [64]. The photosensitizer is the key for photodynamic therapy. Conventional photosensitizers include porphyrins, chlorin, and bacteriochlorin/phthalocyanines. However, due to low hydrophilicity and possible aggregation, traditional photoactive molecules are limited in biomedical applications. It is thus urgent to improve the photosensitizers' water solubility and biocompatibility [65].

The emergence of nanomaterials provides a new aspect in developing photoactive molecules. They can be used as new carriers for photoactive molecules and improving the photosensitizers' biocompatibility. Moreover, the self-targeting nanomaterial enables sufficient photosensitizer enrichment in the tumor tissue, improving tumor therapeutic effects, and reducing the photosensitizer's adverse effects [66]. Recently, gold nanomaterials, carbon-based nanomaterials, and silica nanomaterials are the major substances in photodynamic therapy. These nanomaterials have a high drug-loading capacity and can efficiently boost tumor photothermal therapy [67]. Besides, photodynamic therapy, chemotherapy, hyperthermia, and other tumor therapies can be integrated by constructing multifunctional nanomaterials to achieve multitherapeutic synergy, which is favorable in cancer treatment [68].

6. Prospect

The constant nanotechnology and magnetic nanomaterial development have made significant progress in cancer diagnostics and therapeutics. Magnetic nanomaterials are widely used in MRI/PET-CT imaging, antitumor drug carriers, magnetic fluid hyperthermia, and different fields. However, their application remains preclinical and yet to be applicable in clinical trials [69]. Primarily, we need a comprehensive study on the multifunctional magnetic nanomaterials' biosafety, distribution, long-term toxicity, synthesis, elemental composition, size, surface modification, and metabolism in vivo. With the rapid development of magnetic nanomaterials, nanotechnology, and biotechnology, magnetic nanomaterials can be widely used in cancer diagnosis and treatment in the future.

7. Conclusion

Magnetic nanoparticles not only have the general characteristics of nanoparticles but also have magnetic properties, which have become the research focus in the field of nanomedicine in recent years. Magnetic nanoparticles are widely

used in biomedicine, drug gene delivery, magnetic resonance imaging, molecular probe, tumor detection, tumor therapy, and other fields due to their unique properties. With the development of nanotechnology, magnetic nanoparticles will be more widely used in tumor diagnosis and treatment.

Conflicts of Interest

The authors declare that they have no conflict of interest in this work.

Authors' Contributions

Xuefeng Bian and Ting Guo contributed equally to this work.

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